

Epitaxial 3C- and 6H-SiC PN Junction Diodes

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OBJECTIVE OF DEVICE RESEARCH:

To advance and improve 3C- and 6H-SiC fundamental device processing and epitaxial growth techniques for use in all SiC-based electrical device structures (e.g., SiC Diodes, MESFET's, JFET's, MOSFET's, SIT's, Thyristors, BJT's, etc.).

APPROACH:

Focus on fundamental pn junction

Fabricate epitaxial 3C- and 6H-SiC pn junction diodes on same 6H-SiC substrate.

Characterize electrical capabilities and identify performance limiting factors

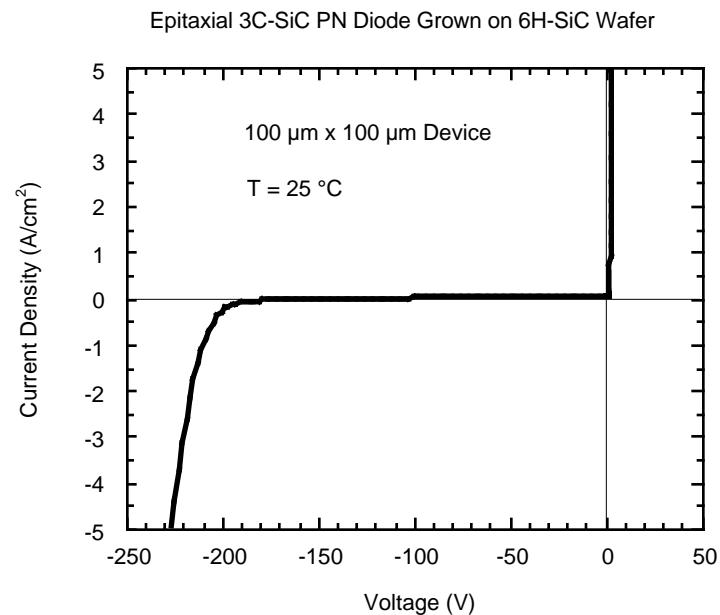
STATUS:

Best 3C-SiC pn diodes ever reported

- Rectification demonstrated to -200 V (4-fold improvement in 3C blocking voltage)
- Green-yellow light emission
- Stacking faults not yet completely eliminated

Excellent 6H-SiC pn diodes

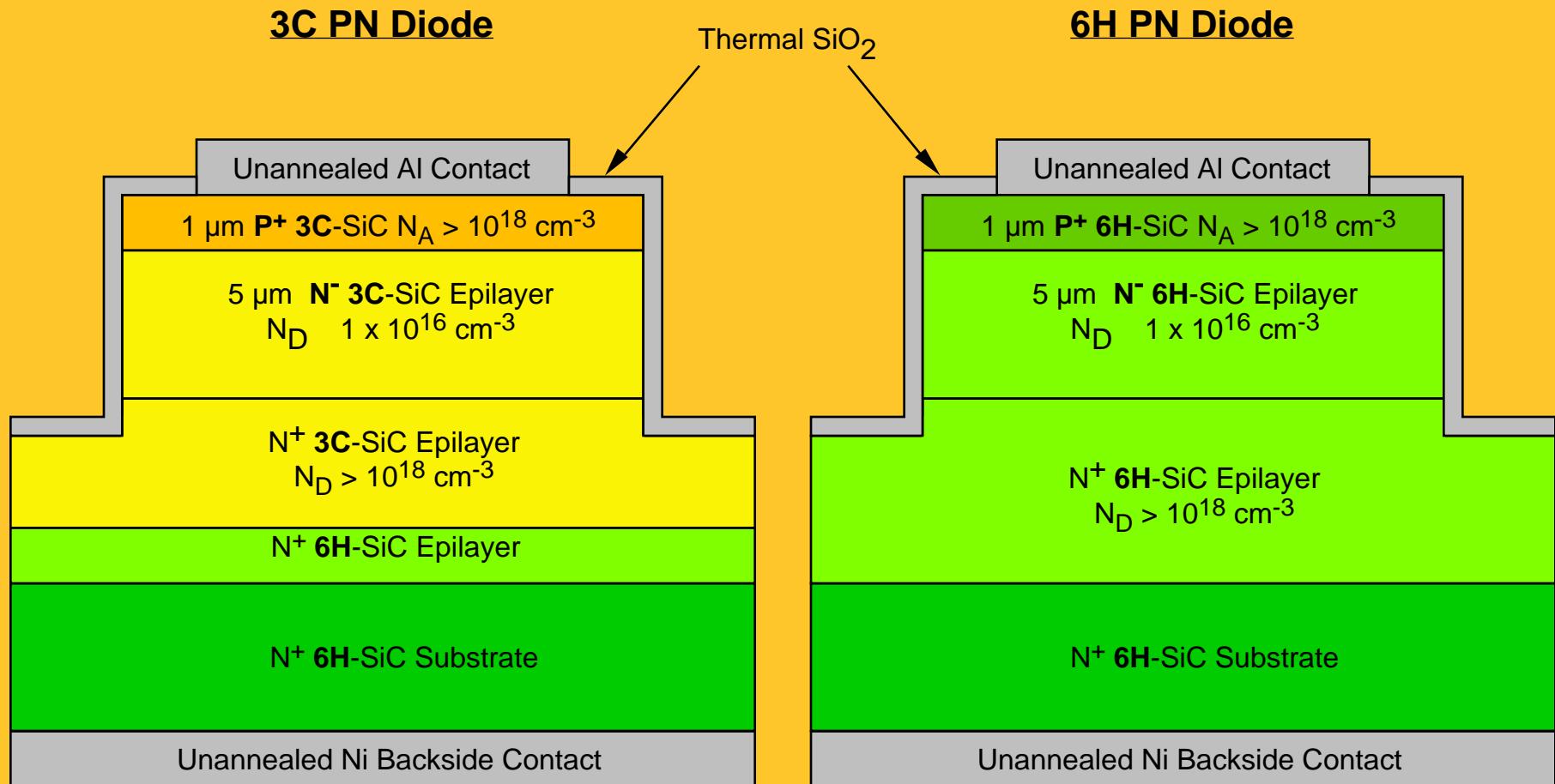
- Reverse leakage of 200 $\mu\text{m} \times 200 \mu\text{m}$ diode at -1100 V < 20 nA (< 50 $\mu\text{A}/\text{cm}^2$)
- Forward current perimeter dominated



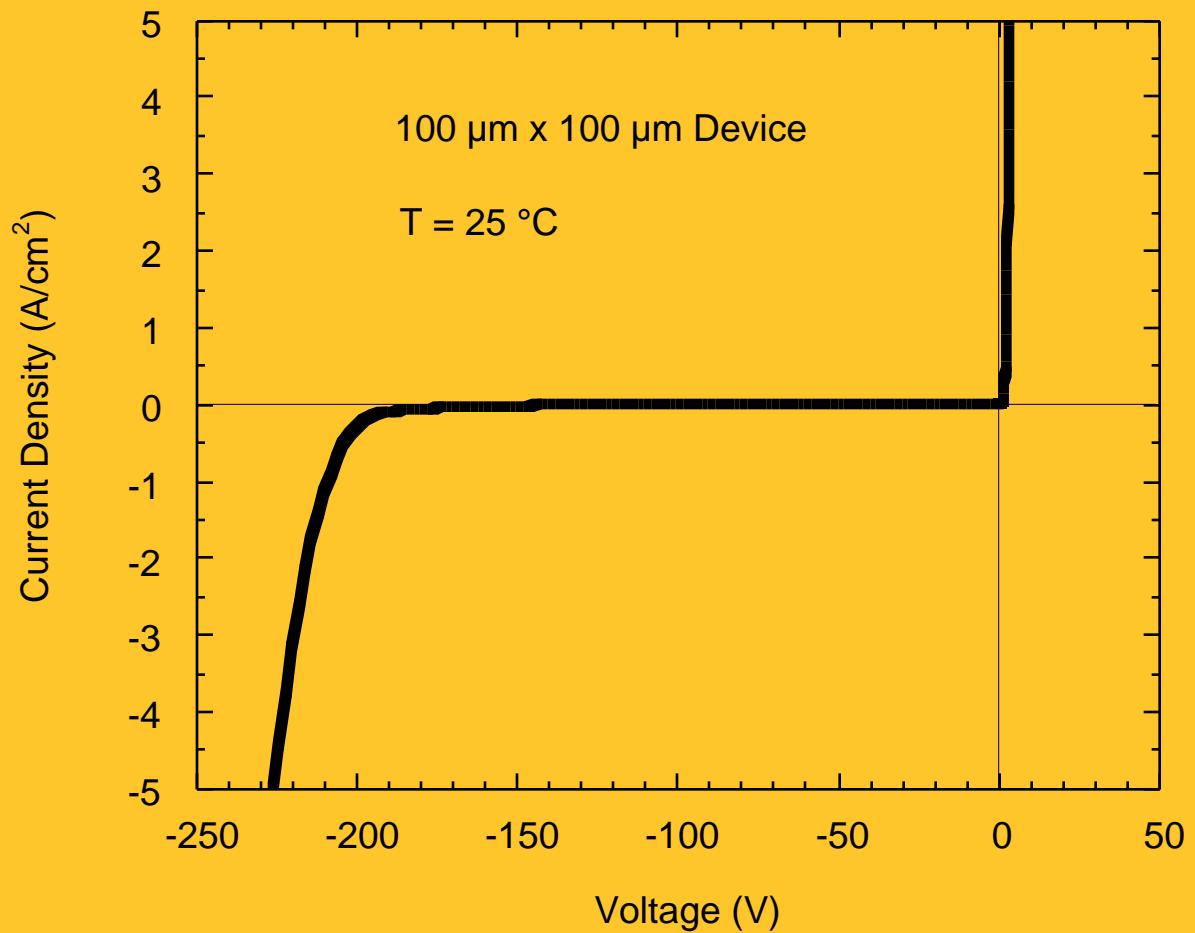
Electrical Characterization of 3C- and 6H-SiC PN Junction Diodes Grown by CVD on Low-Tilt-Angle 6H-SiC Wafers

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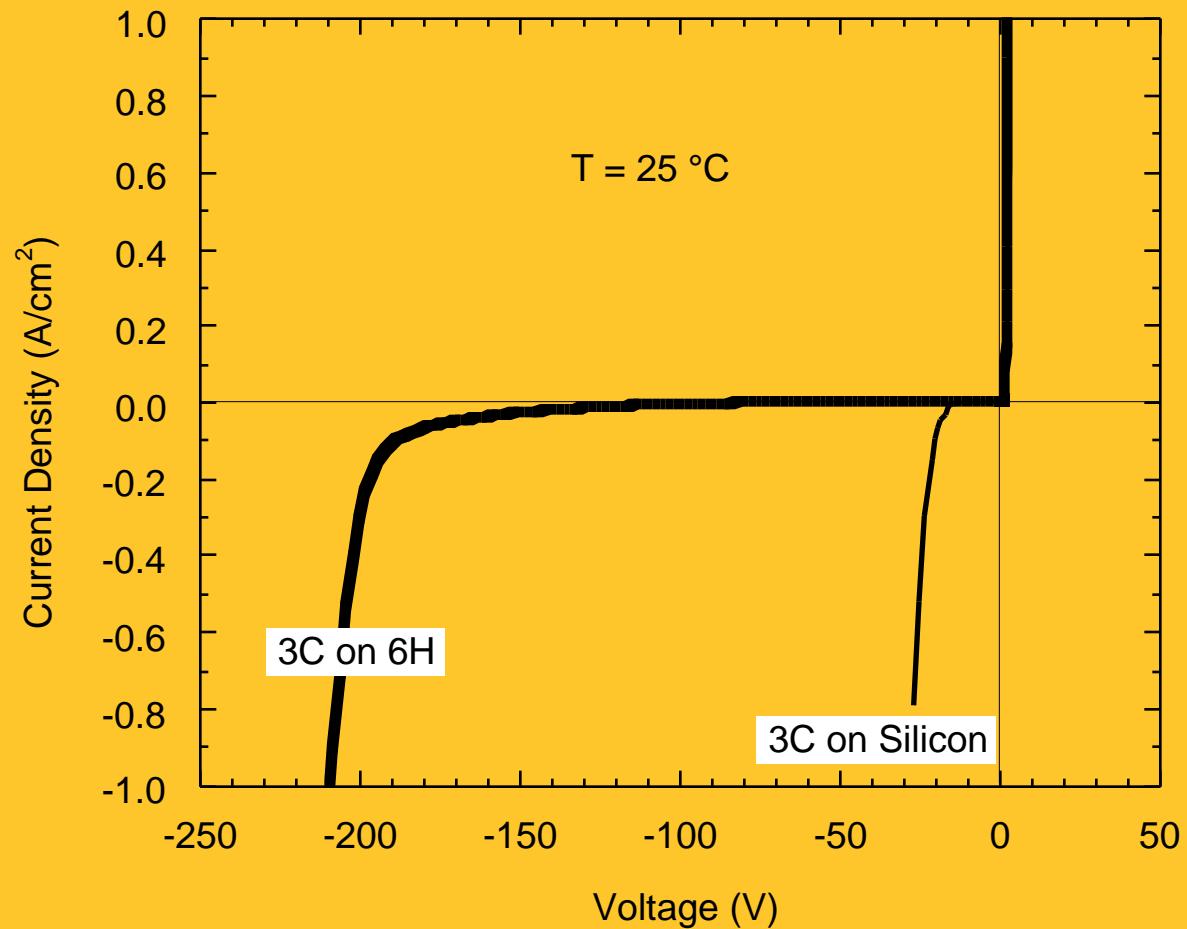


Epitaxial 3C-SiC PN Diode Grown on 6H-SiC Wafer



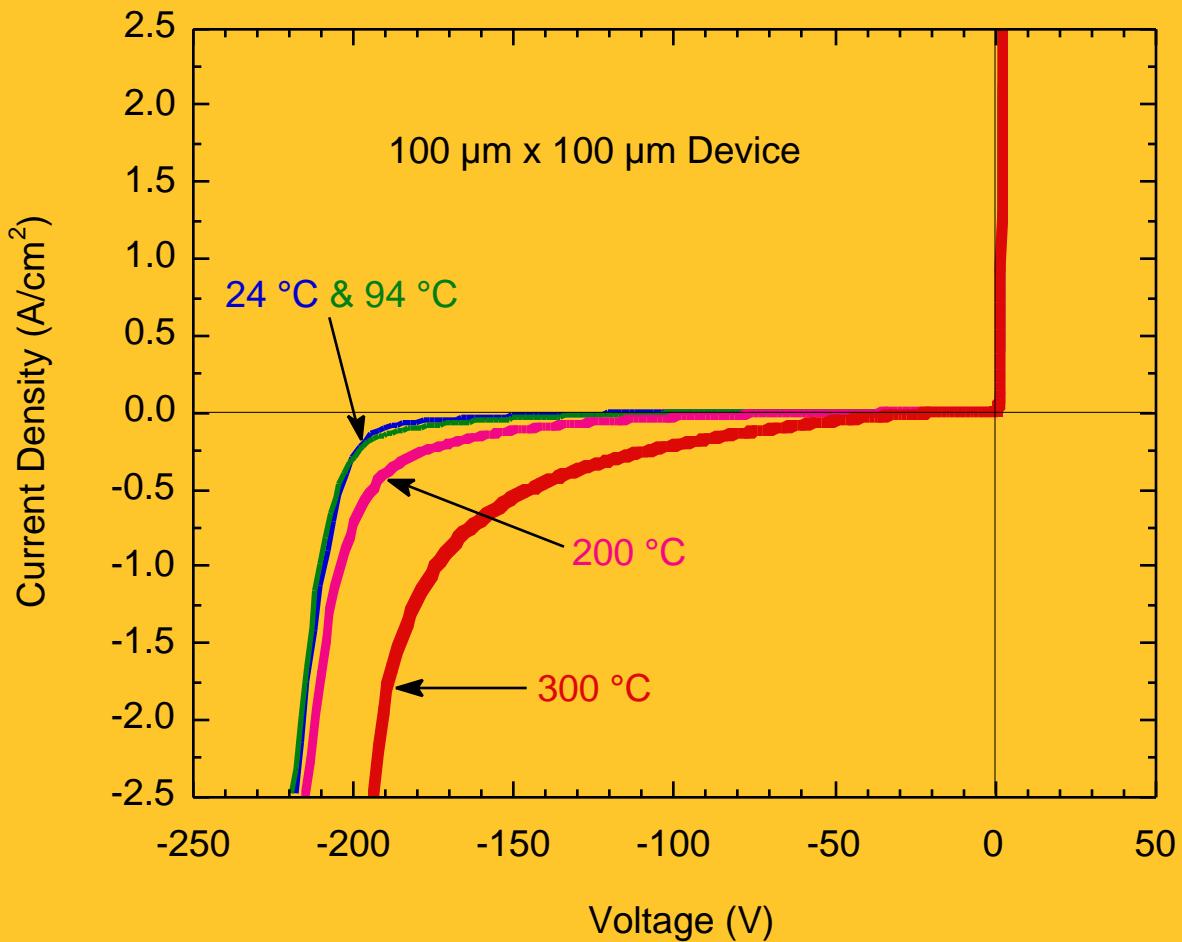
P. Neudeck et. al.
Unpublished Data
1992

Improvement in 3C-SiC PN Diode Characteristics



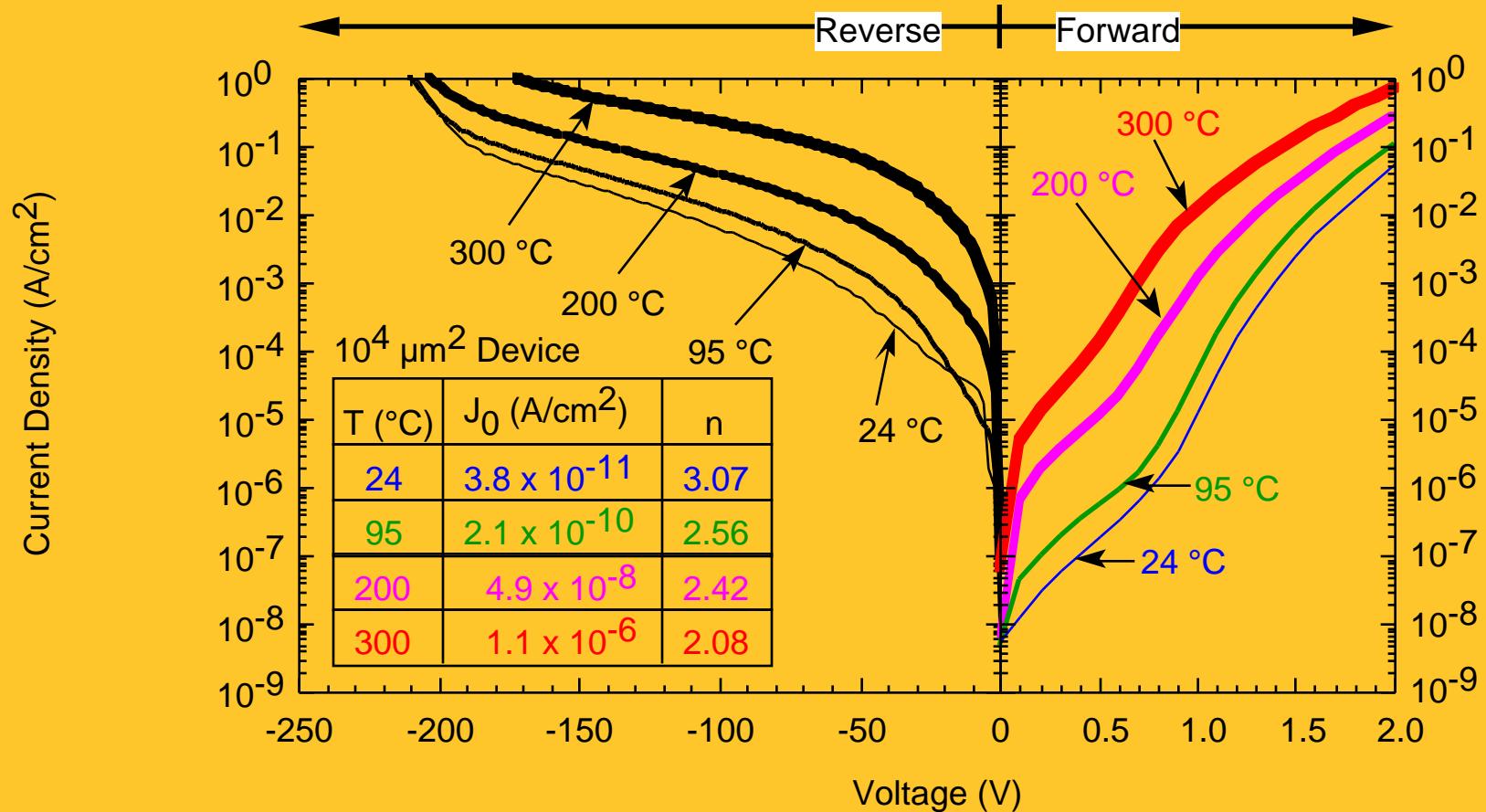
P. Neudeck, D. Larkin, J. Starr, J. A. Powell, C. Salupo, and L. Matus
NASA Lewis Research Center, Unpublished Data 1992

Temperature Performance of Epitaxial 3C-SiC PN Junction Diode



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3C PN Diode Characteristics on a Logarithmic Scale

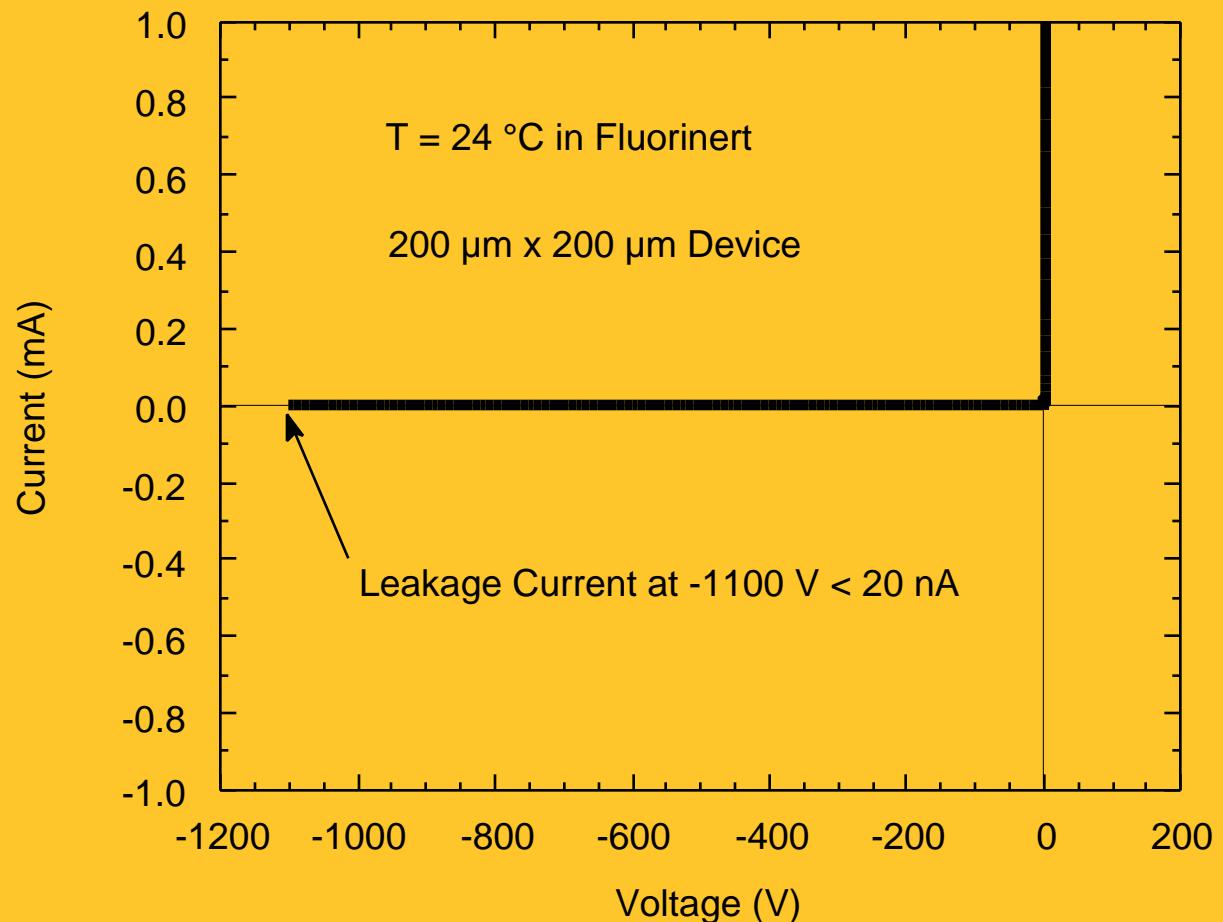


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Though Vastly Improved, NASA 3C-SiC PN Diodes Are Far From Ideal

- DBP's eliminated. Stacking faults significantly reduced, but not eliminated.
- Leakages significantly reduced, but still excessive for wide band gap semiconductor.
- Record 200 V rectification demonstrated, but breakdown remains "soft".
- 3C on 6H epilayer growth is not as well-developed as 6H on 6H epilayer growth, but considerable progress has been made.

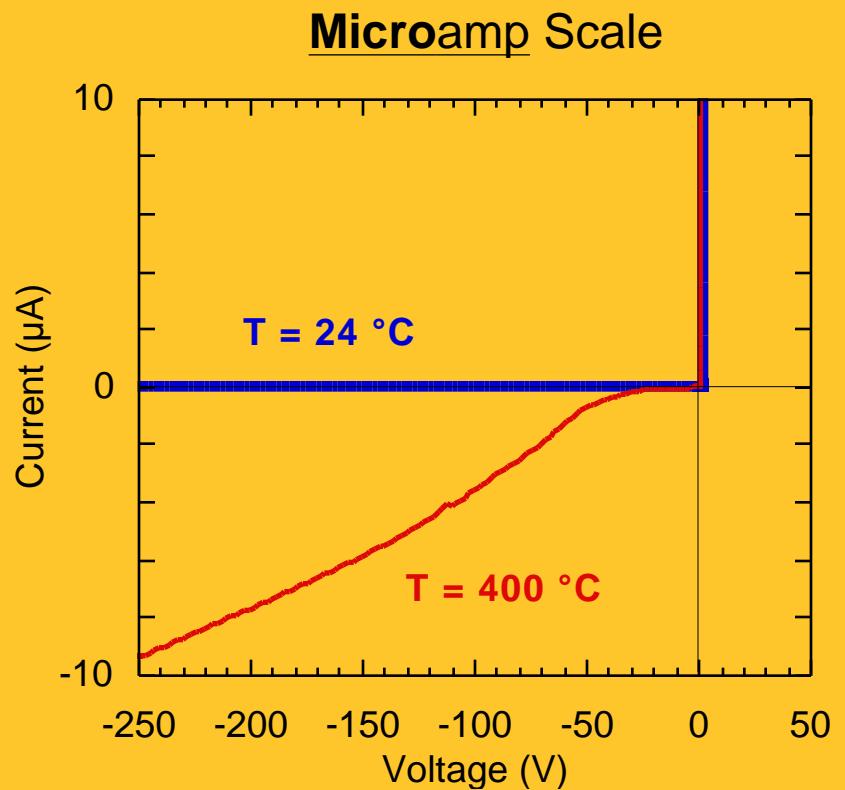
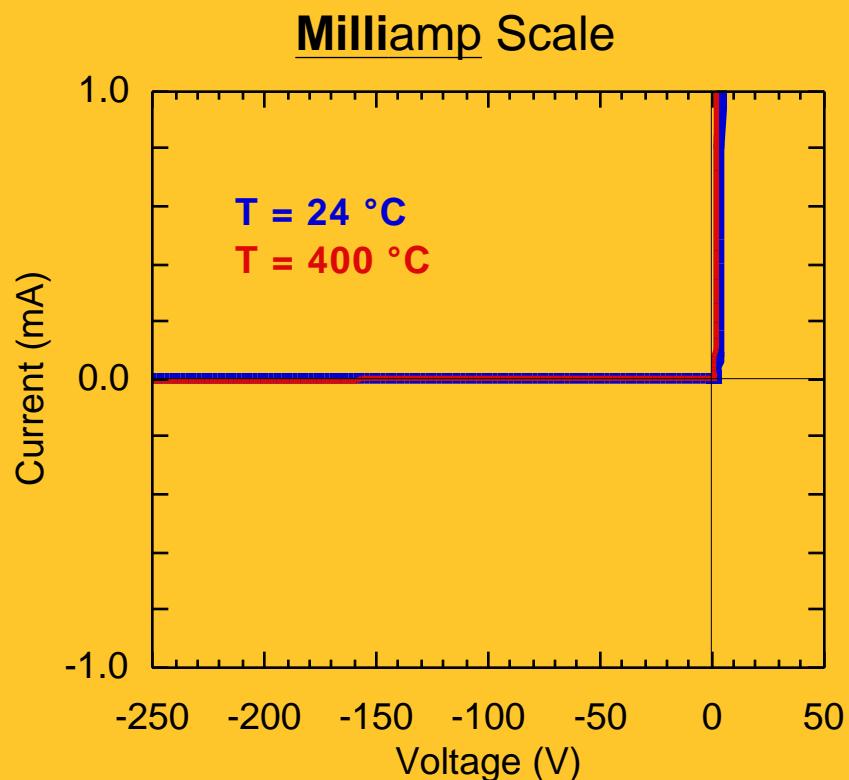
On-Axis 6H-SiC PN Diode



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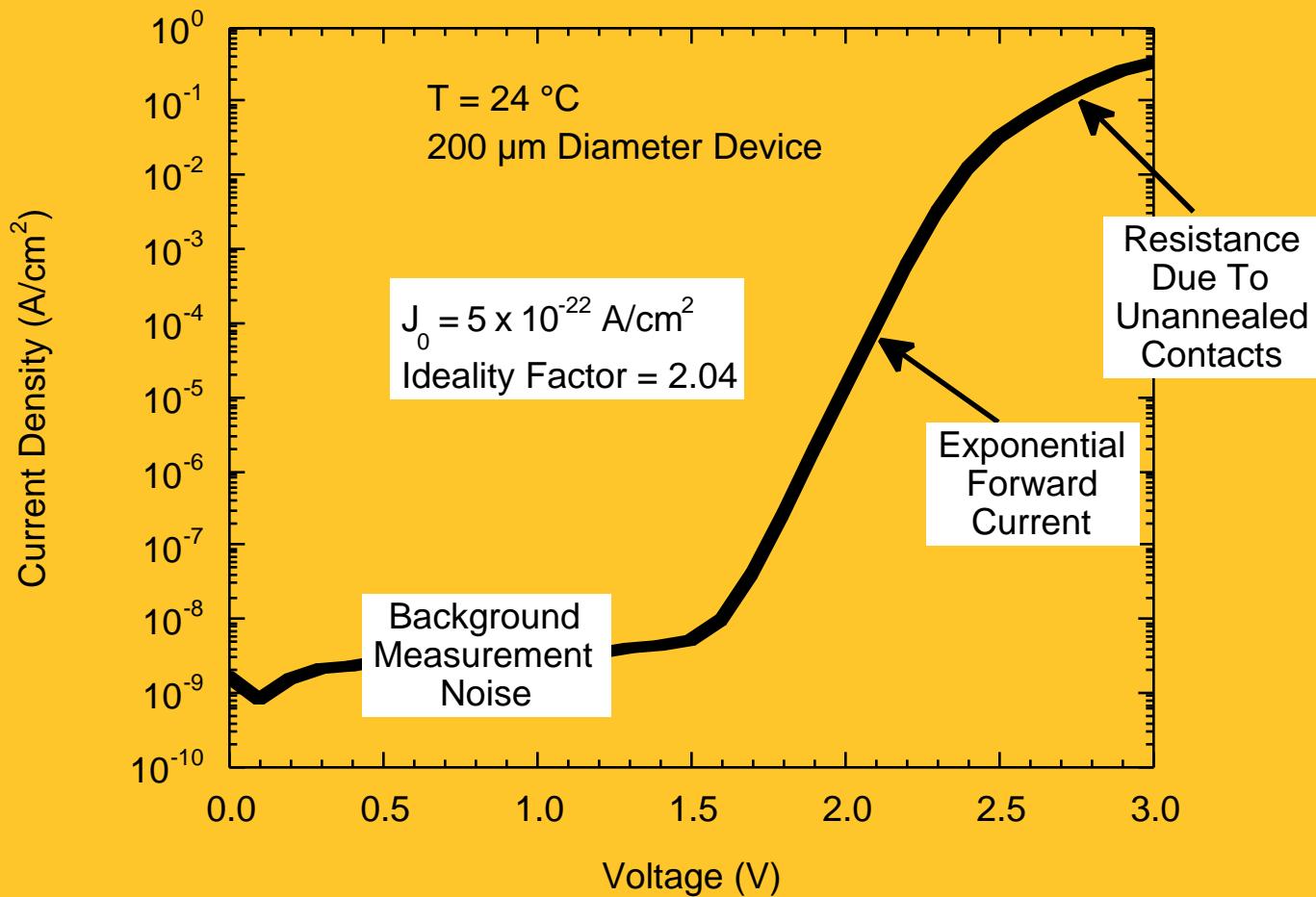
200 μm Diameter NASA 6H-SiC On-Axis PN Junction Diode

(Measured in Air)



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On-Axis 6H-SiC PN Diode Forward Characteristics



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Perimeter Recombination Current:

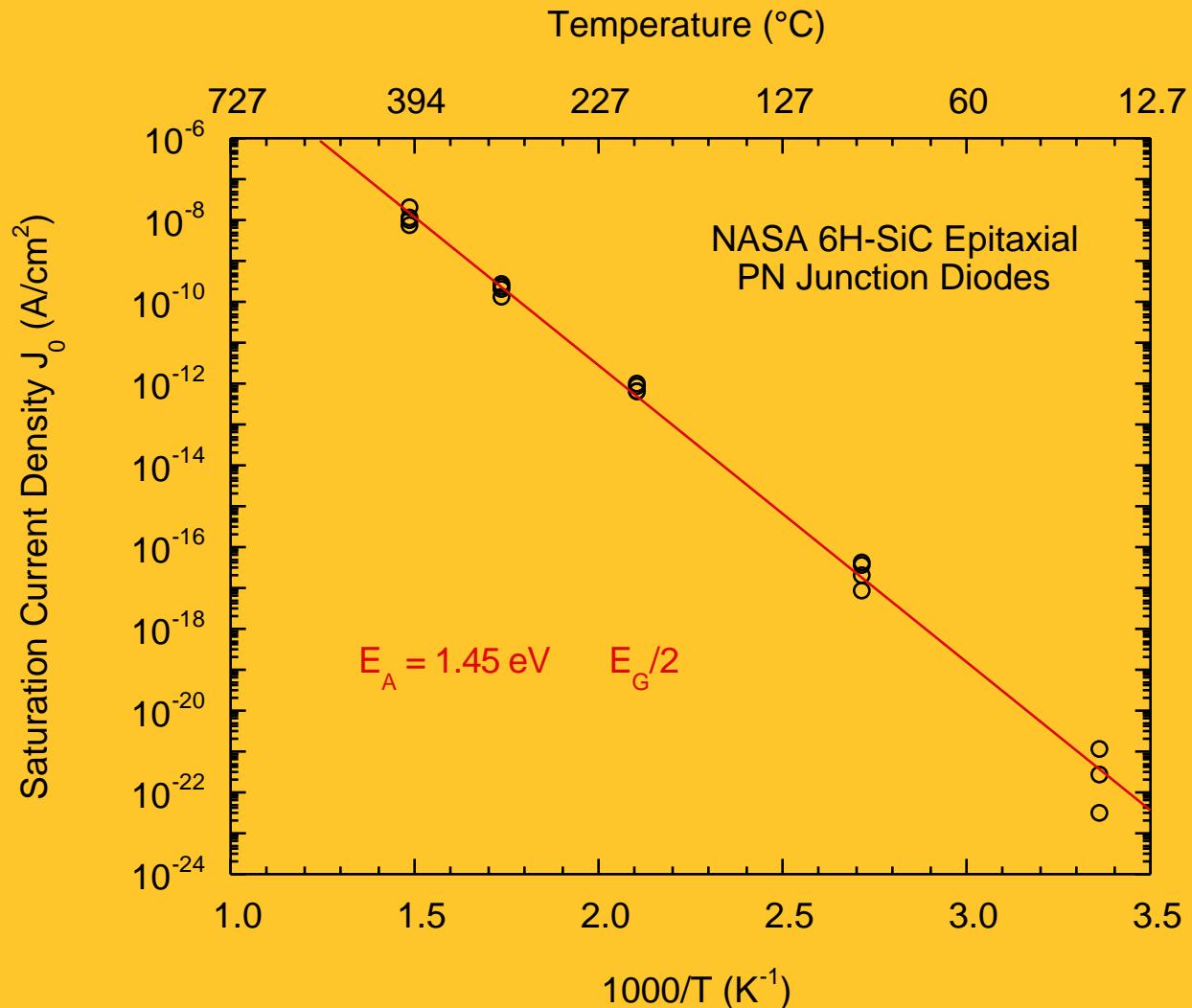
$$\begin{aligned} I_{\text{Perim. Rec.}} &= qP \int_{-x_p}^{x_n} R_S(y) dy = qn_i s_0 L_S W_{\text{eff}} P (e^{qV/n_s kT} - 1) \\ &= J_0 P (e^{qV/n_s kT} - 1) \end{aligned}$$

Bulk Recombination Current:

$$\begin{aligned} I_{\text{Bulk Rec.}} &= qA \int_{-x_p}^{x_n} R_B(y) dy = \frac{qn_i W_{\text{eff}}}{0} A (e^{qV/n_b kT} - 1) \\ &= J_0 A (e^{qV/n_b kT} - 1) \end{aligned}$$

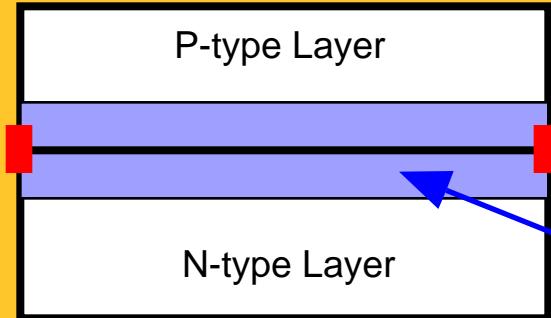
Typically:

- 1.) Temperature dependence dominated by $n_i = \sqrt{N_C N_V} e^{-E_G/2kT}$
Activation Energy of $J_0 = \frac{E_G}{2}$
- 2.) $n_s, n_b \approx 2$ Ideality Factor ≈ 2

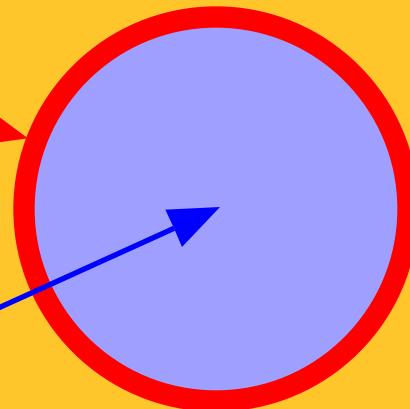


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Side View of Diode



Top View of Diode



Perimeter
Recombination

Bulk
Recombination

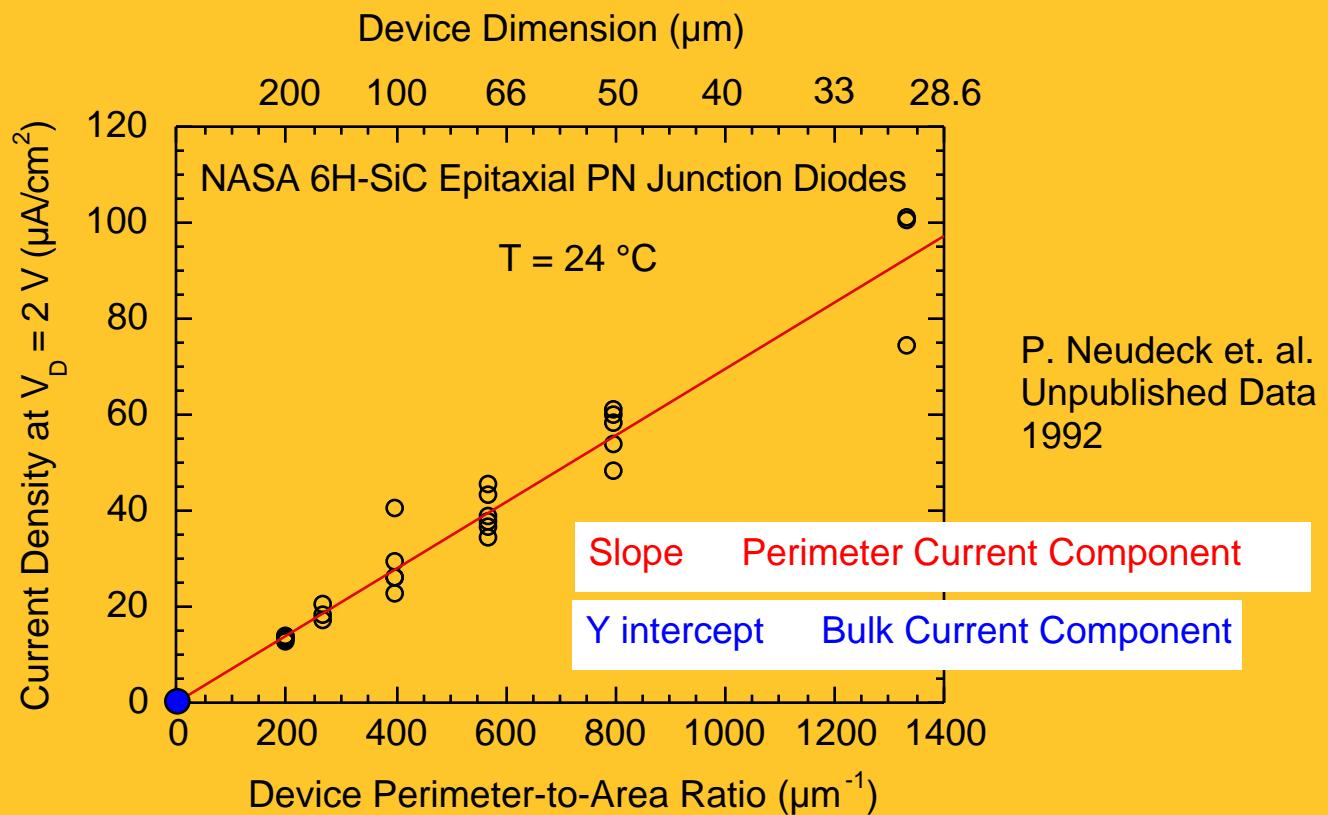
$$\begin{aligned}\text{Current} = I_{\text{Diode}} &= I_{\text{Bulk}} + I_{\text{Perimeter}} \\ &= (J_{\text{Bulk}} * A) + (J_{\text{Perimeter}} * P)\end{aligned}$$

$$\text{Current Density} = \frac{I_{\text{Diode}}}{A} = J_{\text{Bulk}} + J_{\text{Perimeter}} * \left(\frac{P}{A} \right)$$

Plot of Current Density (J) vs. Perimeter-to-Area Ratio (P/A)

Y intercept Bulk Current Component

Slope Perimeter Current Component



Zero Y-intercept indicates that **bulk recombination current** is unmeasurably small compared to **surface recombination current** at room temperature.

First-Order Calculations:

- Bulk lifetime $\tau_0 > 5 \times 10^{-8} \text{ s}$ (limit of measurement scatter error)
- Surface recombination velocity $s_0 = 5 \times 10^5 \text{ cm/s}$

Summary

Best 3C-SiC pn junction diodes ever reported

- Rectification demonstrated to -200 V
(4-fold improvement in 3C blocking voltage)
- Green-yellow light emission
- Much room for improvement remains
 - Stacking faults not yet completely eliminated

Excellent 6H-SiC pn junction diodes

- Reverse leakages of less than $50 \mu\text{A}/\text{cm}^2$ at -1100 V demonstrated
- Bulk recombination insignificant compared to perimeter recombination
- Half band gap activation energy observed